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THE THERMAL ENVIRONMENT OF THE TERRESTRIAL PLANETS
(Supplement 5)

by KLAUS SCHOCKEN
  Research Projects Laboratory

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George C. Marshall

Space Flight Center,

Huntsville, Alabama

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ABSTRACT

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        B. W. Hapke has prepared surfaces which reproduce the lunar light scattering curve. He found that any dark powder can be used for this purpose, provided the grains are of the order of a few microns in size and are shaken through a grating on a surface so that they will fall individually. Then the grains stick to other grains on contact, since the van der Waals forces will be more important than the gravitational forces. It appears likely that the lunar surface layer possesses a structure of this type.

        The determination of the surface pressure of the Mars atmosphere yields 17 ± 3 mb.

        Spectral measurements of the solar X-ray emission were made with a Bragg crystal spectrometer in an Aerobee rocket. No line was detected below 13 Å.

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RESEARCH PROJECTS DIVISION

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SUMMARY

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I. VENUS

Using a balloon-telescope vehicle, a reflection spectrum of the clouds of Venus was obtained. The spectrum covers the region between 1.7 and 3.4 micron.

The 30-cm aperture telescope was carried to 26.2 km and directed toward Venus by offset sun tracking and automatic guiding. A coarse grating was used to produce a spectrum of low dispersion.

Spectra were taken for a period of $3\frac{1}{4}$ hours on October 28, 1964. The result was compared with reflection spectra of liquid water, ice, silica sand, liquid formaldehyde, oil, solid carbon dioxide, frozen carbon dioxide cloud, frost, clouds of water droplets and ice crystals in the laboratory. Agreement was found with the spectra of ice crystal clouds at temperatures comparable to those of the clouds on Venus, as shown in Fig. 1. A correction based on estimates for absorption by gaseous carbon dioxide and water in the region above the Venusian clouds would give an even closer agreement.

The conclusion can be drawn that the reflecting cloud layer on Venus is composed of particles of frozen water [1].

Three models of the Venus atmosphere have been discussed previously (MTP-RP-62-7). The greenhouse model (#1) has been modified in the following way.

A phase variation exists producing a surface temperature difference between the dark and light sides of at least 70°K. The pressure at cloud level on the light side is equal or greater than the pressure at the cloud level on the dark side. At cloud-top the CO_2 mixing rate is approximately 0.05 to 0.15. The dark side cloud altitude is 80±20 km; the altitude on the bright side should be somewhat higher. The main reflection surface is the visible cloud layer, which possesses a temperature of 234°K. The pressures are 90 mb on the dark and 608 mb on the light side.

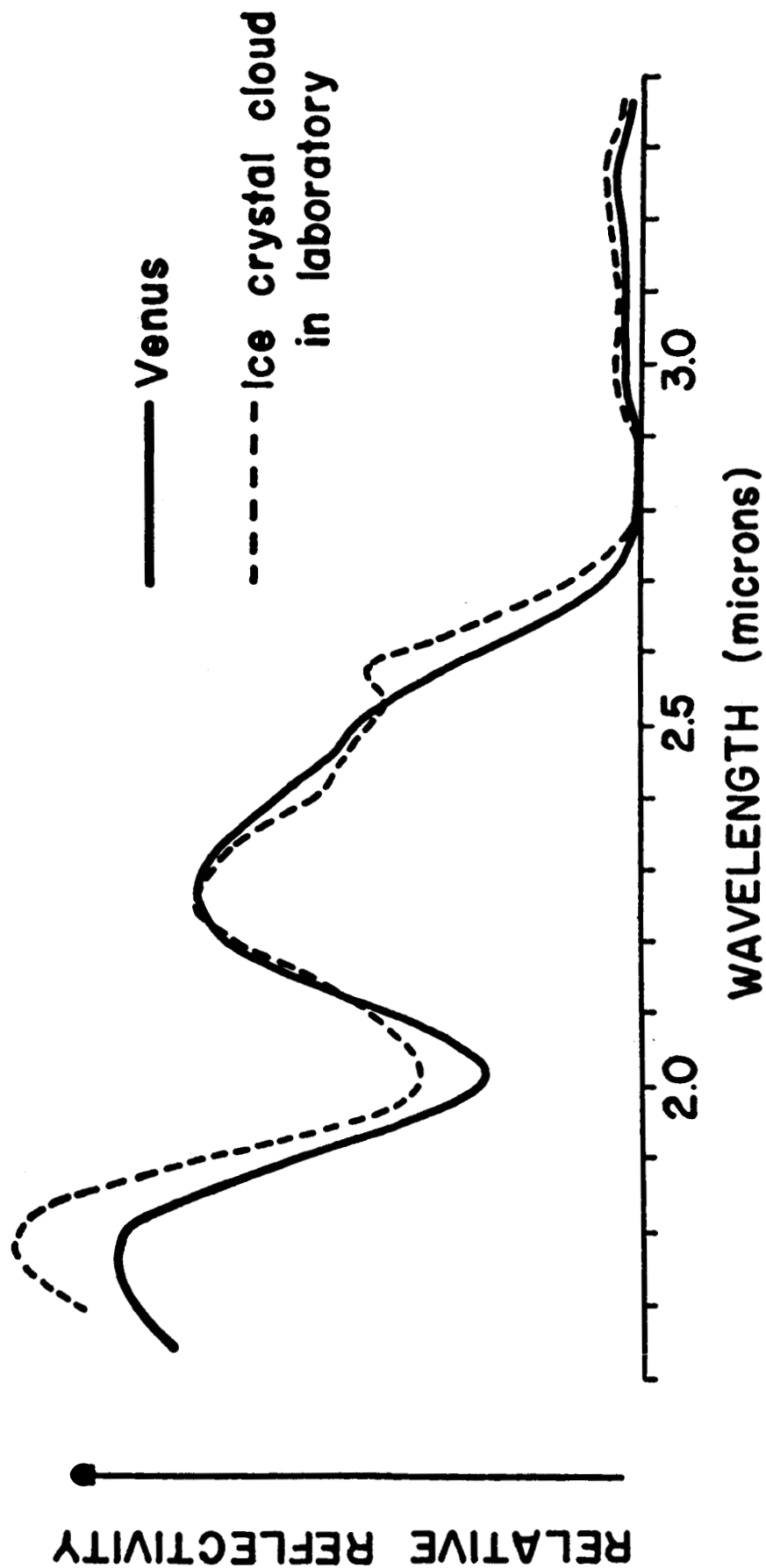At the occulation level, the temperature is 203°K and the pressure

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FIGURE 1 - Reflectivity of Venus atmosphere compared with ice crystal cloud

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is $2.6 \cdot 10^{-3}$ mb. The occultation of Regulus occurred 55 ± 8 km above the visible cloud layer.

The surface temperature of the bright side is $750°K$, that of the dark side $640°K$. The surface pressure is at least 30 atmospheres. The lapse rate is between $\frac{1}{2}$ and 1, on the dark side 0.67 times the dry adiabatic lapse rate. No significant water vapor exists under these conditions. A surface wind velocity of 0.15 to 0.10 m sec^{-1} is required to carry the necessary energy from the light to the dark side. The high temperatures and pressures provide the necessary cloud opacity. With the resulting Rayleigh scattering, the only wavelength which could reach the surface in breaks in the turbulent cloud cover is near infrared [2].

Spectroscopic investigations have shown unambiguously only the presence of carbon dioxide. In Venus spectrograms, no Doppler-shifted O_2-lines were found. A relative molecular oxygen abundance of smaller than $8 \cdot 10^{-5}$ has been found; for the Earth it is 0.23 [3].

It has been postulated that the solar wind exerts an influence on the atmospheres of Mercury and the Earth (NASA TMX-53138(1964)). If this is the case then it is to be expected that an influence will also exist on the atmosphere of Venus.

It has been suggested that hydrogen from the solar wind has been captured in the outer parts of the Earth's atmosphere, and that the Earth, largely by virtue of the effect of its magnetic field upon the solar protons, has accumulated $1.7 \cdot 10^{23}$ g of hydrogen during its lifetime of 10^{17} sec. This amount of hydrogen oxidized to water equals closely the known ocean mass of $1.5 \cdot 10^{24}$ g.

The total interception of protons during the lifetime of Venus may be estimated. The measured proton flux is 10^9 cm^{-2} sec^{-1}. The area of Venus is 10^{18} cm^2. The estimated age of Venus is 10^{17} sec. Hence, the interception amounts to $10^{9+18+17} = 10^{44}$ protons, which is equivalent to about 10^{21} g of cloud material. This quantity of material could account for the observed Venus cloud cover. The absence of a magnetic field on Venus allows the solar wind to impinge on the atmosphere of Venus diectly.

Solar hydrogen must be expected to react with the components of the Venus atmosphere as the solar wind streams in and penetrates the

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atmosphere. These reactions form carbon-hydrogen and nitrogen-hydrogen bonds and may result ultimately in yields of significant amounts of hydrocarbon and amino compounds. Large amounts of condensed products from this source could account for the permanent cloud layer of Venus.

The absence of a magnetic field, combined with the estimated slow retrograde rotation of Venus of 240 days provide the conditions for the reaction of hydrogen of solar origin with components of the upper atmosphere, leading to the ultimate production of a stable cloud layer composed of a hydrocarbon-amide type polymer covering the entire surface of the planet [4].

II. THE EARTH

In interplanetary space, the intensity-mass distribution of micrometeorites is represented by the following relation:

$$\log I = -17 - 1.7 \log m,$$

for the mass range of 10^{-7} to 10^{-10} g, where I represents the flux of particles per m^2 per sec and m the mass of the particle in g. The data indicate a value of about $1\ m^{-2}sec^{-1}$ at a mass of 10^{-10} g near the Earth. In interplanetary space, a flux of about $7 \cdot 10^{-5}\ m^{-2}\ sec^{-1}$ has been found. This decrease by 4 orders of magnitude is an indicator of the existence of a dust cloud near the Earth [5].

The Earth is the only terrestrial planet on which molecular oxygen is present in large amounts. The terrestrial oxygen in the present, second-generation atmosphere is produced by photosynthetic activity of present-day plants and by the photo-dissociation of water, with the hydrogen escaping. No important amounts of oxygen can be expected to outgas from the Earth's interior, since the surface rocks are suboxidized and absorb oxygen. Free oxygen should not have been present in the primordial atmosphere of the Earth formed with nearly the solar composition. The abundant elements C, N, and O should have been present as CH_4, NH_3, and H_2O [3].

III. THE MOON

Through the partial atmospheric window at 16 to 24 microns, continuously recorded emission spectra from four lunar surface features modified by the atmospheric absorption, were obtained. The sample size on the Moon, was approximately 80×480 km^2, the noise level was less than 1% and the resolution better than 0.4μ. The features were central Highlands, Serenitatis, Copernicus, and Tycho. It was concluded that the comparative differences in intensities of the recorded spectra are due to the superimposition of differences in spectral emission from the lunar surface materials upon the absorption of the atmosphere and result from compositional differences between the lunar features examined [6].

The microwave brightness temperature has been measured over the lunar disk, using a 1.5-m aperture Cassegrain telescope. The measurements cover a broad band centered at 1.5 mm. The results of two series of lunar drift curve measurements are shown in isothermal form in Figs. 2 and 3. The measurements show a much greater poleward darkening than that found from infrared measurements [7].

Owing to the close coincidence of the lunar equator with the ecliptic, the surface temperature maintained by solar radiation, which means the temperature to the order of magnitude of 1 m, will decrease from the equator to the poles. Due to the dependence of the conductance on temperature, the temperatures within the solid layer are then not equalized as the depth increases. The differences at 200- to 300-km depth turn out to be about twice as great as at the surface. A difference of $150°$ in sub-surface temperature between the equator and poles leads to a difference of about $200°$ in the mean temperature of the solid layer.

Lower temperature at any part of the layer is accompanied by an increase of its radial thickness. Solidification at the poles extends about 50 km deeper than at the equator. Since the density of solid matter exceeds that of its liquid form, isostatic adjustment of the outer layer as a whole will lead to a flattening at the polar regions. There would be further increase by the greater thermal expansion of the equatorial material owing to its higher temperature. The stresses in the solid layer after its isostatic adjustment would be sufficiently small to be
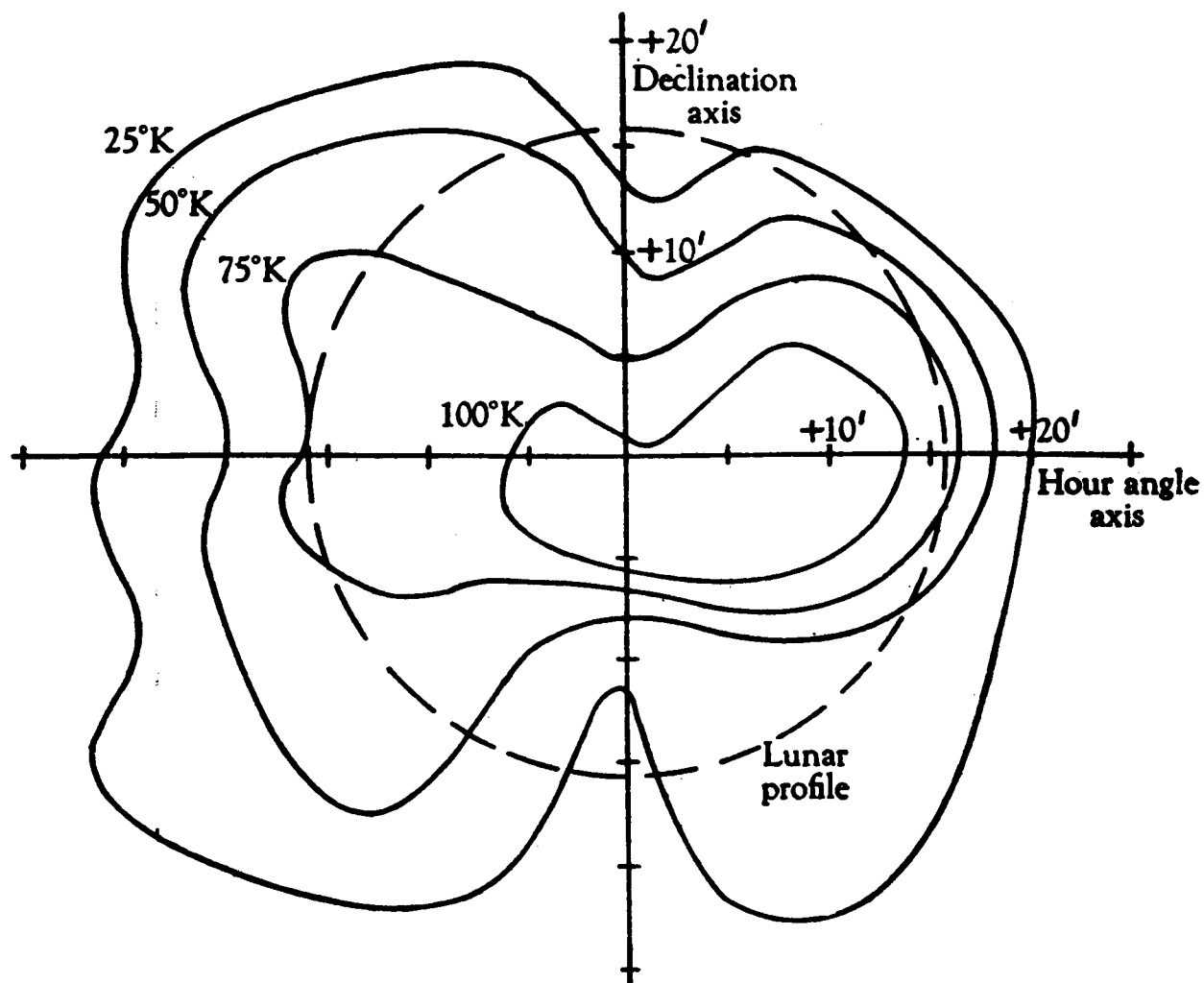
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FIGURE 2 - Lunar microwave isotherms at 1.5 mm. Phase: 45° after new moon. Detector: indium antimonide photoconductor at 1.7°K. Entrance aperture of 8 mm giving angular response function of approximately gaussian form with standard deviation 5.0 min of arc.
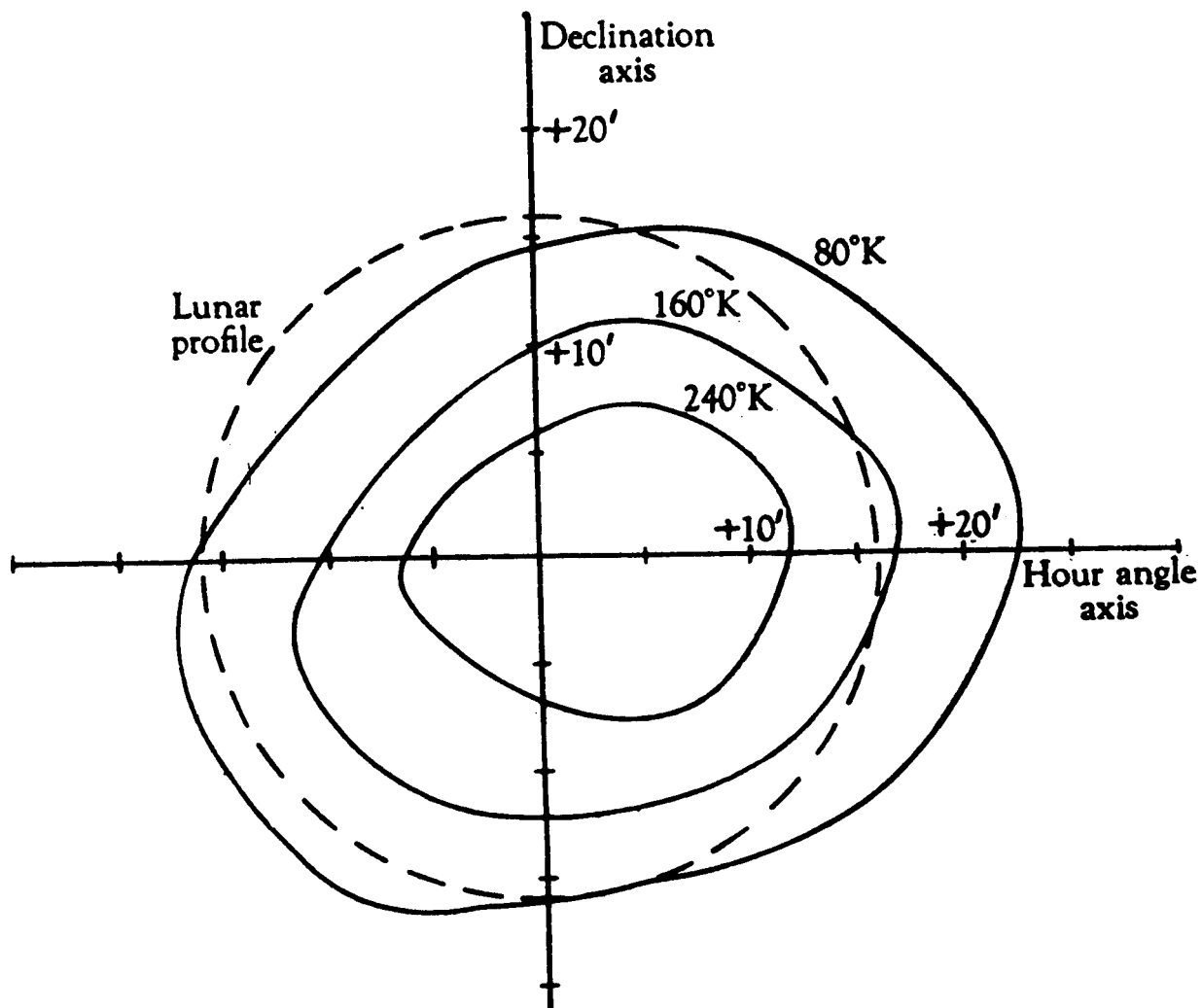
FIGURE 3 - Lunar microwave isotherms at 1.5 mm. Phase 136°after new moon.
Detector: Golay cell. Entrance aperture of collecting cone 15 mm,
giving angular response function of approximately gaussian form,
with standard deviation 8.4 min of arc.

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capable of permanent support by rigidity [8].

The telescopic observations of the lunar surface indicate that, on the scale of 1 km and greater, it is essentially smooth and its average inclination to the horizontal direction does not exceed one-tenth. The radar echo studies indicate that a similar degree of smoothness persists all the way down to a scale-length of the order of 10 cm or less.

The steepness of the lunar light curve and an effective absence of limb darkening at optical frequencies necessitate for their explanation a surface which is highly vesicular; the observations previously mentioned have relegated the roughness to the mm-domain.

Polarimetric measurements of scattered moonlight suggest that the outermost layer of the lunar surface is covered everywhere with a very fine dust of 2 to 3 microns average grain size which appears to cling equally to all parts, regardless of their slope.

It appears tentatively that all essential properties of the lunar surface can be explained satisfactorily by different manifestations of a dust swept up by the Moon from interplanetary space on its journey around the Sun. The color of the Moon is very nearly uniform and gray, as would be expected from a largely uniform layer of dust. The albedo varies by a factor 3 between extreme values, but this is much less than the differences in reflectance encountered among common terrestrial rocks. This near uniformity of the observed lunar albedo suggests the influence of cosmic dust intermingled with local debris produced by larger meteor impacts. The smallness of the overall lunar albedo is probably due to the radiation damage produced by the Sun on a surface unprotected by an atmosphere.

Finely divided rock dust in an extremely loose state of compaction meets every requirement for reproducing the lunar photometric laws, except that terrestrial rock powders are not sufficiently dark. It is difficult to make rock particles as small as 10 μ opaque. Probably the hydrogen ion bombardment of the solar wind is able to darken the rock powders sufficiently. Darkening is due to the reduction of the metal oxides to free metal by the sputtering action of the ions, but other darkening processes may be required to account for the lunar photometric laws. Micrometeoritic bombardment of the primordial lunar surface material will produce a layer of fine dust a few centimeters

thick. When a micrometeorite hits this layer of dust, some particles will be thrown a large distance, but many more will be moved only short distances of the order of 1 mm. Thus the dust will be fluffed up and built into a loosely compacted state. The bulk density of the material is only $\frac{1}{10}$ that of solid rock. The depth of the dust layer must be at least a few millimeters.

An accretion rate of 1 g cm^{-2} for particles with masses less than 10^4 g impacting on the Moon during the past $4.5 \cdot 10^9$ years is consistent with the available data. The flux of interplanetary bodies has probably remained fairly constant during most of this time. The major contribution to the accreted material comes from particles with masses between about 10^{-5} and 1 g. Their dimensions are between 0.1 and 1 mm. These particles are primarily of cometary origin and are very fragile. The densities of the particles are of the order of 0.5 g cm^{-3}.

B. W. Hapke has prepared surfaces which reproduce the lunar light-scattering curve. He found that any dark powder can be used for this purpose, provided the grains are of the order of a few microns in size and are shaken through a grating on a surface so that they will fall individually. Then the grains stick to other grains on contact, since the van der Waals forces will be more important than the gravitational forces. The resulting structure has a bulk density between $\frac{1}{7}$ and $\frac{1}{10}$ of the density of the crystalline powder. It appears likely that the lunar surface layer possesses a structure of this type [9].

IV. MARS

A composition model of the Mars atmosphere is listed in Table 1. The determination of the surface pressure yields 17 ± 3 mb [10].

Three tentative models of the Mars atmosphere have been developed — a maximum, a minimum, and a mean. The parameters which were used in a computer program for the three models are shown in Table 2 [11].

The south polar cap on Mars disappeared during its perihelion opposition in 1956. Up to September 28, 1956, the appearance of the cap was normal. On the night of August 29-30, it became less clear,

TABLE I

Composition Model of Martian Atmosphere

Gas	Abundance cm, NPT	Volume Fraction
N_2	30 000	0.85
CO_2	5 000	0.14
Ar	400	0.01
H_2O	1	
O_3	<0.05	
O_2	<7	
SO_2	<0.003	
CO	<1	
COS	<0.2	
CH_2O	<0.3	
N_2O	<0.08	
NO	<20	
$N O_2$	<0.0008	
H_2S	<7.5	
$C H_4$	<0.4	
NH_3	<0.1	

TABLE II

Standard Model Atmosphere Parameters for Mars

Parameter	Units	Maximum Model 1	Mean Model 2	Minimum Model 3
Surface pressure	mb	40	25	10
Composition	CO_2 % by mass	7.5	16	60
	N_2 % by mass	92.5	84	40
	CO_2 % by volume	4.9	10.8	48.8
	N_2 % by volume	95.1	89.2	51.2
Molecular weight		28.8	29.7	35.85
Acc. of gravity at surface	cm sec^{-2}	375	375	375
Surface temperature	°K	300	250	200
Troposphere lapse rate	°K km^{-1}	-3.636	-3.89	-4.55
Tropopause altitude	km	11	18	22
Stratosphere temperature	°K	260	180	100
Top of stratosphere	km	150	150	150
Thermosphere lapse rate	°K km^{-1}	2	2	---
Surface density	g cm^{-3}	$4.62 \cdot 10^{-5}$	$3.57 \cdot 10^{-5}$	$2.16 \cdot 10^{-5}$

took on a yellowish tint, and became bordered by an unusually contrasting polar fringe. On blue photographs taken on August 30 it was invisible. At 21 h UT on August 31 the cap disappeared and the region became covered by a yellowish fog. With the use of a red filter, a remnant of the cap could be observed as an insignificant brilliant spot on the following days. At the same time, only small white spots appeared at the original location of the cap. On September 7, the cap was again visible, even without a filter. Its dimensions increased, and on September 15 it had recovered its normal appearance and brightness. These observations indicate that the cap, or a large part of it, disappeared and was renewed in the first ten days of September.

These phenomena can be explained by the influence of the exceptionally strong solar activity after August 20 and the flare on August 31, 1956. The disappearance of the cap can be explained by the fact that during extraordinary cosmic and sub-cosmic particle emission from a flare an increase in temperature occurred which led to the sublimation process of crystals of which the cap consists [12].

V. INTERPLANETARY SPACE

On July 25, 1963, spectral measurements of the solar X-ray emission were made with a Bragg crystal spectrometer in an Aerobee rocket. The spectrometer consisted of a single crystal of potassium acid phthalate as the diffracting element, a Geiger counter detector, and a mechanism to rotate the crystal and detector in a 1 : 2 ratio.

No line was detected below 13 $\overset{\circ}{A}$ with an intensity as great as 10^4 photons cm^{-2} sec^{-1}. All the observed lines are listed in Table 3. The estimated accuracy of the intensities is $\pm 50\%$. [13].

TABLE III

Solar X-ray Spectrum Recorded by Bragg Spectrometer

Wavelength Observed Å	Laboratory Measurement Å	Intensity Above Atmosphere 10^4 photons $cm^{-2} sec^{-1}$	Element
13.7	13.820	1.4	Fe XVII
15.0	15.012	11.7	Fe XVII
15.25	15.261	7.2	Fe XVII
16.0	16.006	4.2	O VIII
16.72	16.774	11.1	Fe XVII
17.01 and 17.05	17.051	14.7	Fe XVII
17.65 and 17.72	17.768	21.0	O VII
18.54 and 18.61	18.627	30.0	O VII
18.8 and 18.9	18.969	23.2	O VIII
20.8	20.910		N VII
21.55	21.602	461.0	O VII
21.70	21.804	212.0	O VII
23.2		31.2	
24.8	24.781	85.2	N VII

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Gerhard B. Heller

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